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GEORGE C. MARSHALL SPACE FLIGHT CENTER

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EFFECTS OF GAMMA RADIATION ON SELECTED POTTING COMPOUNDS AND INSULATING MATERIALS

by

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ABSTRACT

Recent radiation tests were performed at the Oak Ridge National Laboratory on the following types of polymeric materials: epoxy, silicone, and polyurethane resins; teflon, polyester film, and Mylar flat-conductor cables. After exposures of up to 10^8 roentgens, mechanical properties were analyzed by the Pilot Manufacturing Branch of Astrionics Laboratory. Property changes data were then correlated with molecular effects caused by absorption of gamma rays. How radiation affects the physical properties of common polymeric materials and the specific material irradiated at Oak Ridge are discussed.

It was found that at the maximum doses to which the subject material was exposed, Mylar and polyester films performed well. Teflon performed very poorly under the same conditions. Among the potting compounds, the epoxy resins showed the effects induced by both chain scission and crosslinking. The silicones changed only slightly in physical properties. Test data indicated a gradual degradation in the properties of polyurethane resins.

This report represents the initial portion of a continuing effort in the evaluation of polymeric materials for use in radiation environments. Present plans call for more extensive testing in combined space environments in the near future.

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SUMMARY

Recent radiation tests were performed at the Oak Ridge National Laboratory on the following types of polymeric materials: epoxy, silicone, and polyurethane resins; teflon, polyester film, and Mylar flat-conductor cables. After exposures of up to 10^8 roentgens, mechanical properties were analyzed by the Pilot Manufacturing Branch of Astrionics Laboratory. Property changes data were then correlated with molecular effects caused by absorption of gamma rays. How radiation affects the physical properties of common polymeric materials and the specific material irradiated at Oak Ridge are discussed.

It was found that at the maximum doses to which the subject material was exposed, Mylar and polyester films performed well. Teflon performed very poorly under the same conditions. Among the potting compounds, the epoxy resins showed the effects induced by both chain scission and crosslinking. The silicones changed only slightly in physical properties. Test data indicated a gradual degradation in the properties of polyurethane resins.

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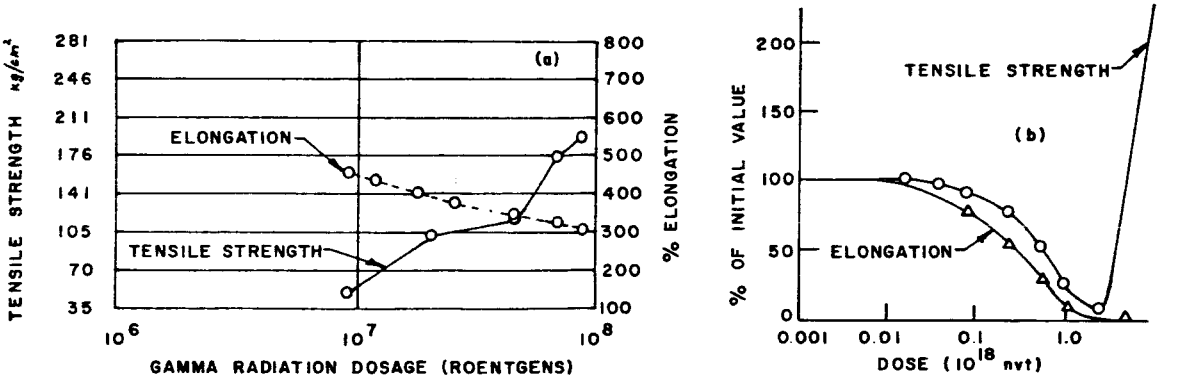
nature of molecular changes can not be based solely on physical property changes. For example, crosslinking draws molecules closer together and increases hardness, so that the resultant material is brittle and glassy. Scission usually causes opposite changes in physical properties by breaking the molecule into smaller fragments, decreasing the molecular weight, and lowering the melting point. The resultant product becomes soft. However, sometimes crystallinity can be increased by polymers that undergo scission because there is less restraint on the shortened molecule. Thus the molecules become more easily oriented in the crystal structure. An increase in crystallinity is analogous to an increase in molecular weight and the resultant product is similar to that of a polymer that undergoes crosslinking.

In natural rubber when crosslinking predominates, tensile strengths sometime increase to a maximum (Fig. 1a) as the polymer reaches the brittle or resinous stage. The initial maximum may not occur, however, and a steady increase in crosslinking density may be accompanied by a steady decrease in tensile strength and breaking elongation (Fig. 1b).



1a - Gamma Radiation (R) on Natural Rubber (uncured)

1b - Neutron Radiation of Natural Rubber (cured with sulfur)

FIGURE 1. RADIATION EFFECTS ON NATURAL RUBBER

Developing radiation resistant systems. The organic systems used for encapsulating and potting are usually highly crosslinked systems. Damage is caused by the chemical breakdown of this network. Resins containing radiation resistant groups such as the phenyl group will resist chemical changes best. Phenolics, epoxies, and silicones containing high phenyl/methyl ratios, and resins cured with styren, have superior radiation resistance. In silicones, the Si-O network is highly radiation resistant. In epoxies and polyesters, the network bonds are slowly broken by radiation at a rate dependent on the exact chemical composition.

All organics will evolve some gas because of radiation, but as long as the gases are limited to CO_2, H_2, O_2, and N_2, they probably will not be injurious to men and equipment. In the case of halogenated plastics, commonly used for fire-retardant systems, the designer should beware of the outgassing of strong acid vapors or free halogens.

SECTION III. CURRENT TEST PROGRAM

The radiation tests discussed were carried out at the Atomic Energy Commission's facilities at Oak Ridge, Tennessee. The source of radiation was Cobalt 60 of 17,000 curies of gamma radiation. The dose rate was 1×10^6R per hour at an ambient temperature of 25° C in an atmosphere of air.

The test procedure used with the subject samples consisted of irradiating samples at doses ranging up to 10^8R. Since the dose rate was 10^6R per hour, it is obvious that 10^7R required 10 hours and 10^8R required 100 hours; no test lasted over 100 hours. Following irradiation, various mechanical tests were performed on the materials by the Pilot Manufacturing Branch; comparisons were made between the materials radiated at different levels. Trends could then be correlated on tables and graphs and evaluated.

It is anticipated that future studies will include radiation tests at 25° C and 760 mm Hg and also at high vacuum and cryogenic temperatures. Following the testing in environmental extremes of temperature, vacuum, and radiation, studies will be made on the mechanical properties and also on electrical properties, including dielectric strength, volume resistivity, dissipation factor, and insulation resistance.

The materials selected for study included polymers of the following categories: (1) polyester films, (2) Mylar cables, (3) Teflon film and tubing, (4) epoxy resins, (5) silicone resins, and (6) polyurethane resins.

The most apparent change in these samples of polyester films is a notable correlation between increasing radiation and decreasing breaking load and tensile strength. There is a net loss in elongation.

Table III. Radiation Effects on Polyester Film.

Spl. No.	Total Dose(R)	No. of Specs.	Width cm(in.)	Thickness cm(in.)	Breaking Load kg(lbs)	Elongation %	Tensile Str. kg cm^{-2}(psi)
1C	None	3	2.54 (1.0)	.0076 (.003)	28 (63)	58	1509 (21,160)
2C	1×10^6	3	2.54 (1.0)	.0076 (.003)	28 (62)	63	1460 (20,900)
3C	1×10^8	3	2.54 (1.0)	.0076 (.003)	27 (60)	81	1395 (19,930)

The samples in Table III showed that, as radiation increased, the tensile strength decreased and the elongation percentage increased. Possibly these property changes are caused by predominance of chain scission over cross-linking.

Table IV. Radiation Effects on Polyester Film.

Spl. No.	Total Dose(R)	No. of Specs.	Width cm(in.)	Thickness cm(in.)	Breaking Load kg(lbs)	Elongation %	Tensile Str. kg cm^{-2}(psi)
1D	None	3	2.54 (1.0)	.00254 (.001)	8.6 (19)	97	1320 (19,000)
2D	1×10^6	3	2.54 (1.0)	.00254 (.001)	7.1 (16)	31	1110 (15,800)
3D	1×10^8	3	2.54 (1.0)	.00254 (.001)	7.3 (16)	20	1140 (16,200)

Table IV shows that at 1×10^6R there is a lowering of tensile strength and breaking load coupled with an increase in elongation. At 10^8R, however, the breaking load and tensile strength are both higher, while the elongation has decreased by 10 per cent. These latter changes strongly suggest a predominance of crosslinking over chain scission (Fig. 1b).

The three polyester films shown in Tables II-IV are identical in all respects except thickness. Apparently the difference in the radiation effects which these materials exhibit is related to the thickness of the film. It has been suggested in the literature (Bolt and Carroll, 1963) that the thinner polyester films are the least vulnerable to damage by radiation. This specific contention was neither proven nor disproven by this study, but, as was pointed out in the previous discussion, there were variations in property changes which occurred in these materials related to sample thickness.

3. Teflon.

Table VII. Radiation Effects on Teflon

Spl. No.	Total Dose(R)	No. of Specs.	Shore Hardness	Breaking Load	Elongation %	Tensile Strength kg cm^{-2} (psi)
1A	None	4	48	7	434	185 (2640)
2A	1×10^5	-	57	Sample destroyed	Sample destroyed	Sample destroyed
3A	1×10^6	-	54	"	"	"
4A	1×10^7	-	Sample destroyed	"	"	"

The data in Table VII show the vulnerability of Teflon to radiation in an oxygen atmosphere. Almost immediately after irradiation began, the sample became too brittle to measure for all parameters except Shore hardness. Even this parameter lost its meaning at 1×10^7R because of the extreme embrittlement of the material.

Teflon is among the organic materials most sensitive to radiation in the presence of oxygen. Tensile strength is reduced to half its initial value at 4×10^6R, and elongation is lost at 2×10^6R. Degradation results from scission and is reported to be much less in vacuum than in air. Future studies should be directed toward testing in vacuum using samples of different thickness. It can be anticipated that thicker samples in vacuum will display significantly higher tolerance to radiation.

B. POTTING COMPOUNDS

Three types of potting compounds were tested in the current series of tests. These include polyurethane, silicone, and epoxy resins. Figures 4 through 8 show the effect of radiation and the compressive strength of these materials.

1. Epoxy resins. The type of curing agent used in curing an epoxy resin has a large effect on the radiation stability of the final product. In general, epoxy resins of high heat-distortion temperatures are more resistant than those having low heat-distortion temperature. In addition, aromatic type curing agents offer the most resistance to radiation.

is small, but probably significant; it suggests that a slight crosslinking has occurred within the material. (2) Samples no. 9 and no. 11 LTV 182** and 602** showed no significant trends because of gamma radiation. Hardness values on these materials were too close to be significant. (3) Samples no. 12 RTV 11 Silicone** showed an initial increase in compression strength at 10^5R followed by a decrease in strength at 1.5 x 10^6R (Fig. 7). Hardness values on this material showed a slight decrease as radiation increased. This data are somewhat inconclusive, but it may suggest that a trend toward chain scission is the predominant effect. (4) Samples no. 10 RTV 881 Silicone** showed only slight variations from the unirradiated material. These changes indicate a slight decrease in strength at 10^5 followed by an increase at 1.5 x 10^6R. Hardness values indicate an initial slight decrease at 10^5 followed by a return to the original value at 1.5 x 10^6R. The decrease in strength and hardness at 10^5 may be caused by initial scission reactions followed by a predominance of crosslinking at 1.5 x 10^6R.

3. Polyurethane resins. These resins exhibit a high degree of resistance to radiation and are reported to be surpassed only by aromatic-cured epoxy resins and phenolic resins in radiation resistance. The radiation resistance of this material is adversely affected by the presence of water which increases the probability of damage.

The polyurethanes illustrated in Figure 8 showed the following trends: (1) Samples no. 4 of Eccofoam FPH Polyurethane** showed a marked decrease in compression strength as radiation increased. This data may indicate a trend toward chain scission of the molecules. (2) Samples no. 8 PR 1538** showed a steady decline in compression strength coupled with a decrease in hardness as radiation increased. This data also suggest that a dominance of chain scission was occurring in the molecules.

Table VIII. Radiation Effects on Hardness Properties of Selected Potting Compounds

	Shore Hardness		
	OR	1 x 10^5R	1.5 x 10^6R
Epoxy C1 75% Flex	80	60	>100
Polyurethane 1538	76	75	70
Silicone RTV11	47	45	42
Silicone LTV182	27	29	30
Silicone LTV602	21	17	18
Silicone EC1663	47	43	47
Silicone RTV881	38	35	37
	Rockwell Hardness (E Scale, 100 kg load, 1/8" ball)		
Epoxy 2850GT	77	66	49
Epoxy 2651	56	49	57

** All samples were 1" diameter x 1" length

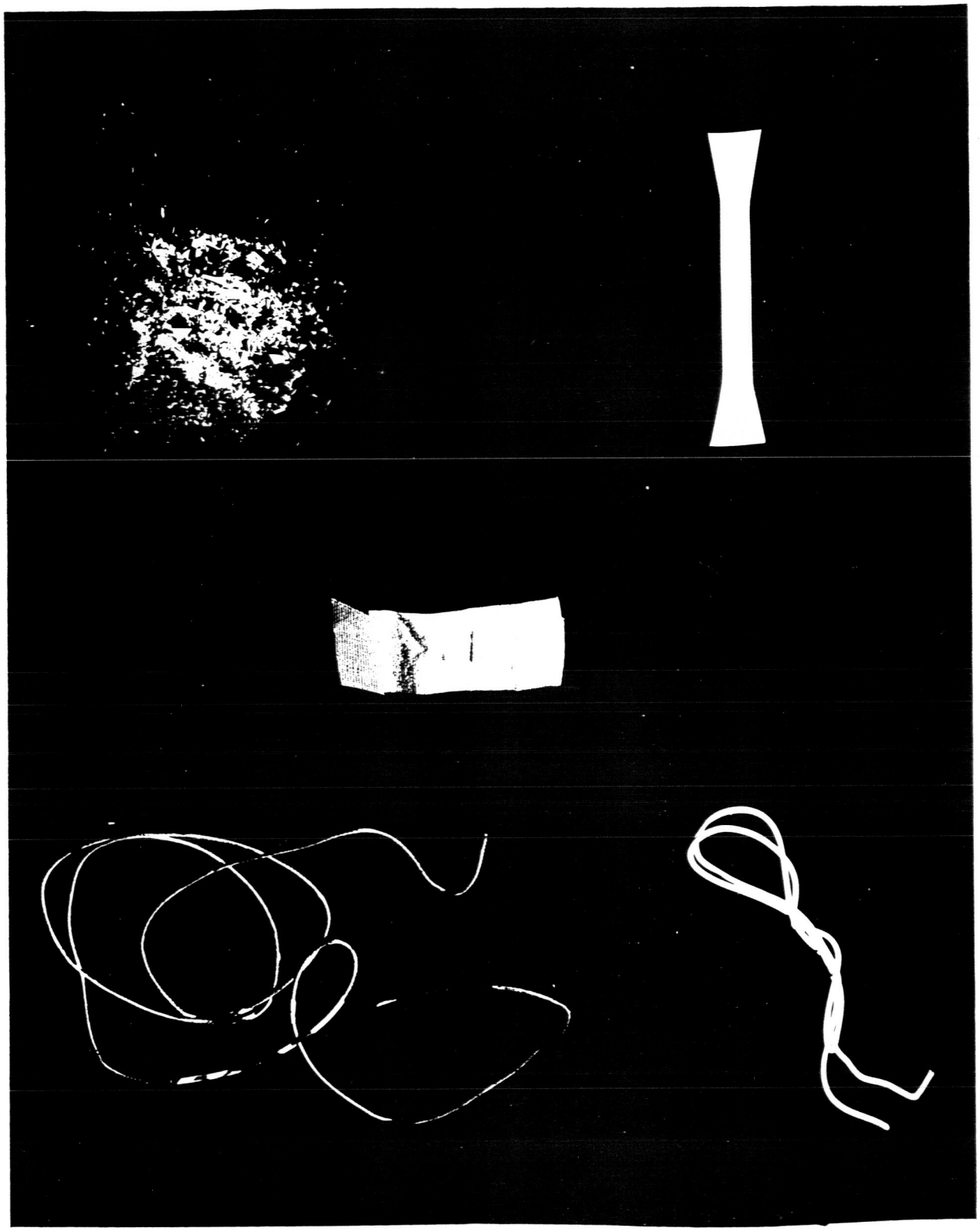


FIGURE 2. RADIATION EFFECTS ON TEFLON AND COPPER FOIL. UPPER LEFT, TEFLON FILM, 10^6R; UPPER RIGHT, TEFLON FILM, 0 R; CENTER, COPPER FOIL, 10^8R (note loss of adhesive); LOWER LEFT, TEFLON WIRE INSULATION, 10^8R; LOWER RIGHT, TEFLON WIRE INSULATION, 0 R.

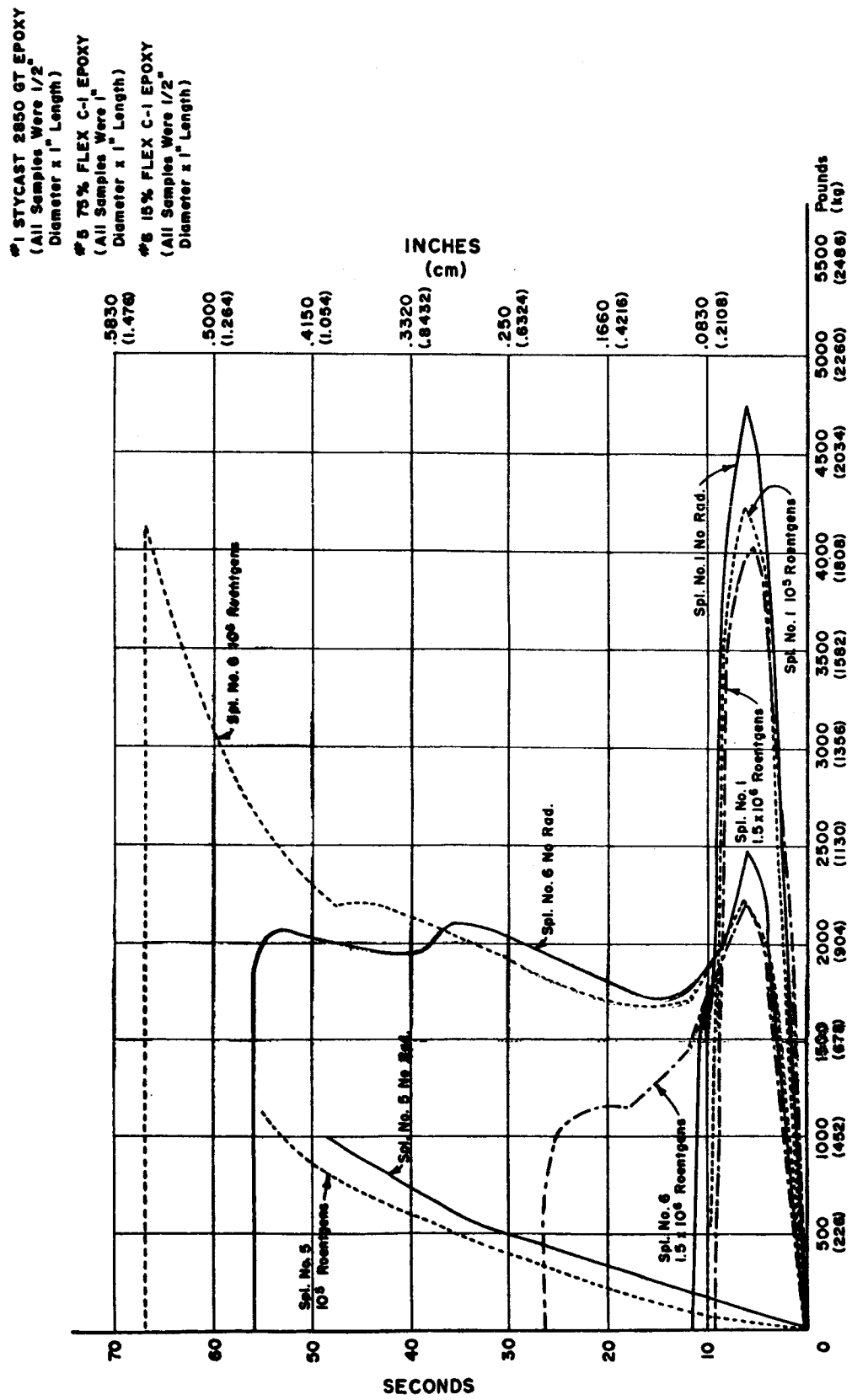


FIGURE 4. RADIATION EFFECTS ON EPOXY RESINS

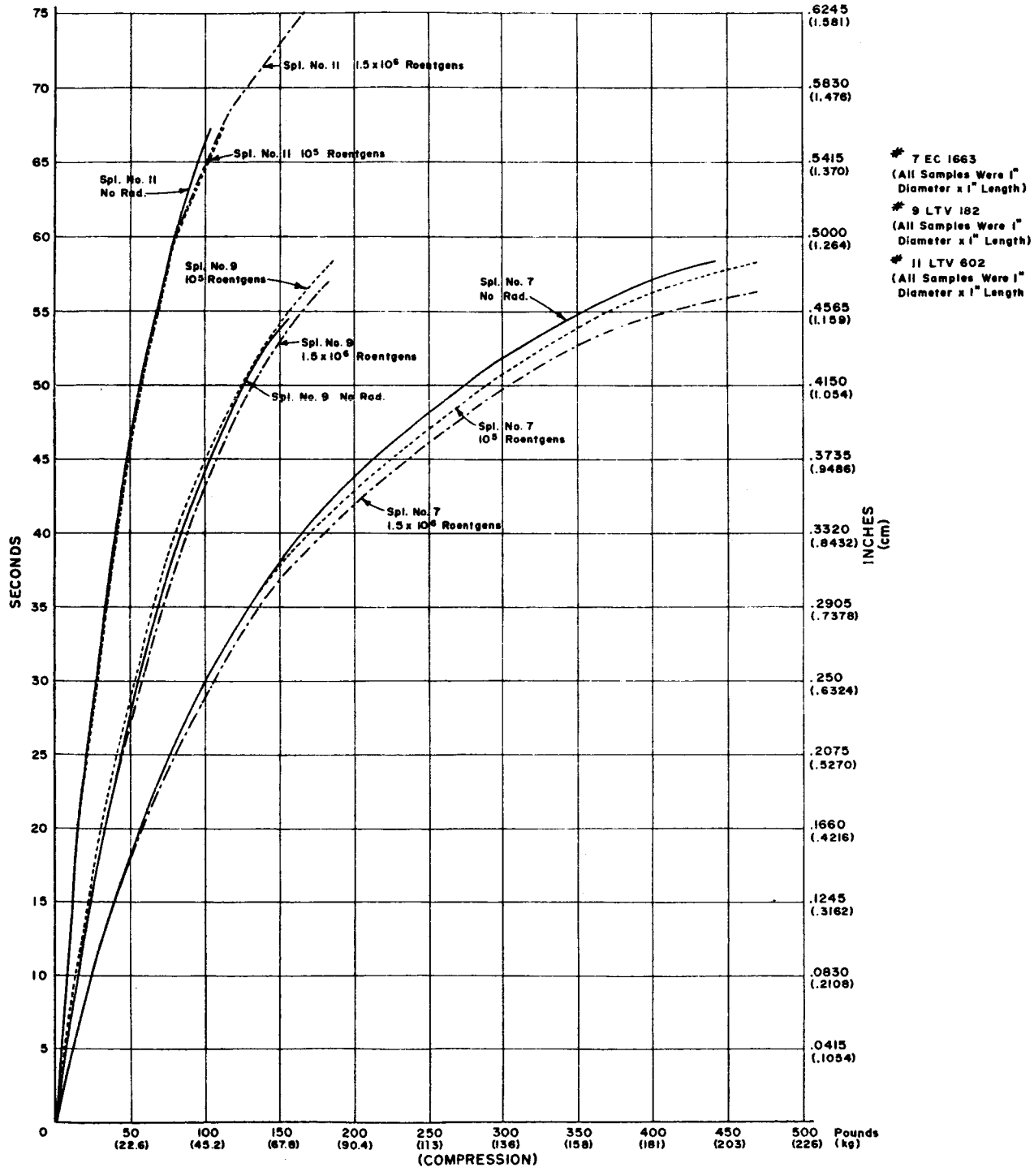


FIGURE 6. RADIATION EFFECTS ON SILICONE RESINS

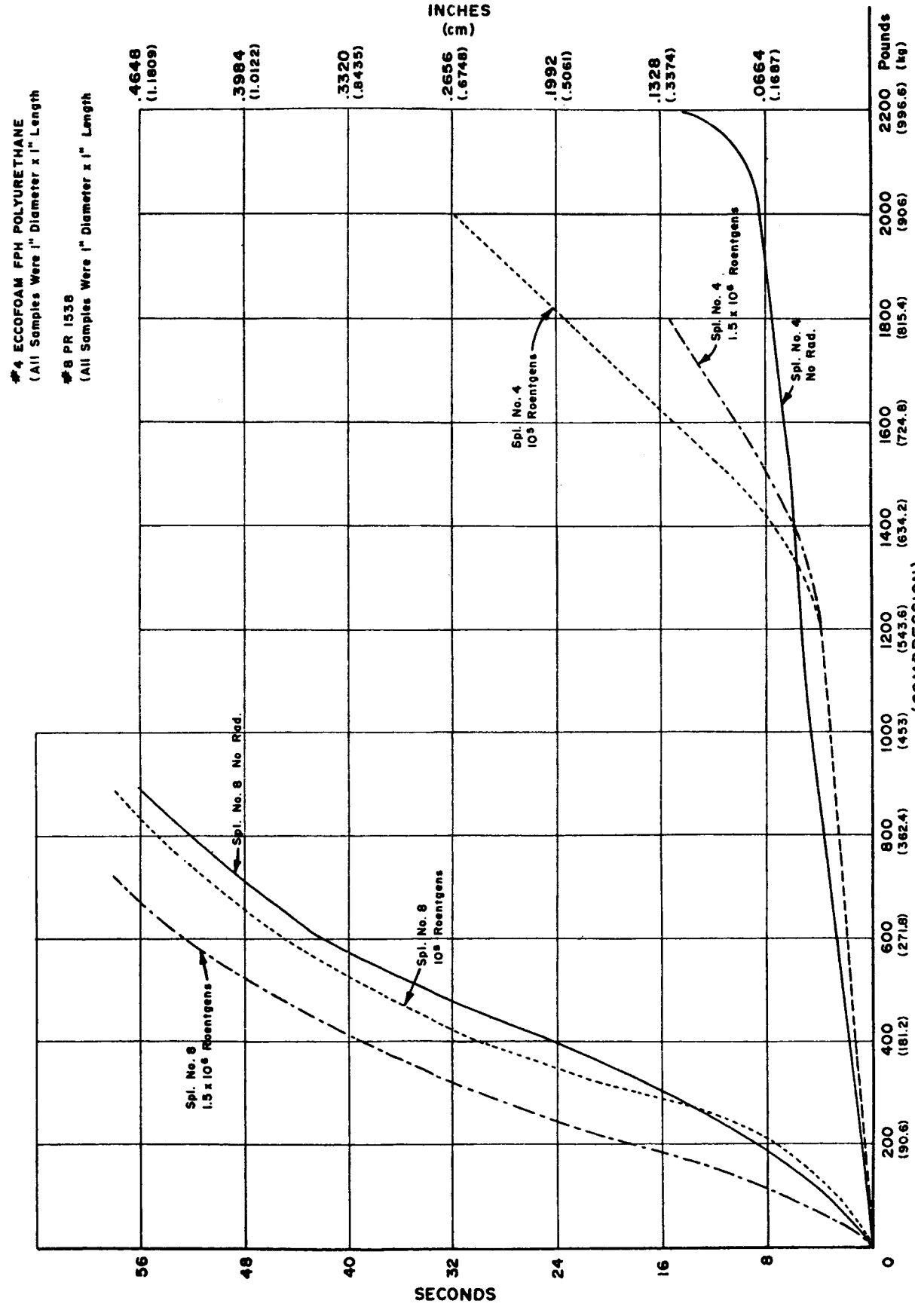


FIGURE 8. RADIATION EFFECTS ON POLYURETHANE RESINS

APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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